THE ISS FLUIDS AND COMBUSTION FACILITY: MICROGRAVITY COMBUSTION SCIENCE AND FLUID PHYSICS RESEARCH CAPABILITY

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Abstract

The Fluids and Combustion Facility is a modular, multi-user facility that will support sustained, systematic microgravity fluid physics and combustion research on board the International Space Station. The FCF Flight Segment includes three on-orbit racks that will be located inside the ISS Destiny Laboratory Module. The FCF Ground Segment includes additional racks that will be used for experiment development and other essential Earth-based capabilities. FCF's design permits highly automated operations to perform high quality microgravity research in space while conserving limited ISS resources, such as crew time. This paper discusses the mission, design and capabilities of the FCF for conducting microgravity research in the ISS and the initial payloads and operation of FCF in ISS.

Introduction

The assembly of the International Space Station (ISS) is well underway and research is now being conducted in the ISS during its assembly phase. The NASA Glenn Research Center (GRC) in Cleveland, Ohio is developing a primary facility for microgravity research on board ISS called the Fluids and Combustion Facility (FCF). The facility will be installed in the ISS Destiny Laboratory Module and will support scientific investigations from the Microgravity Fluid Physics and Microgravity Combustion Science Programs.

FCF's mission success will be measured by its capability to perform research investigations, its economy of operation, its ease of use by Principal Investigators (PI), astronauts and operators, and its annual scientific productivity. The FCF is designed to support research utilization in ISS at a rate of ten or more scientific investigations per year. With sufficient ISS resources, the FCF will also support commercial payloads, International Partner utilization and research from other microgravity science disciplines. FCF's ten-year life cycle may be extended to fifteen years through hardware and software maintenance and upgrades.

The FCF System consists of a Flight Segment and a Ground Segment. The FCF Flight Segment will occupy three rack locations in the ISS Destiny Laboratory Module. These racks are the Combustion Integrated Rack (CIR), the Fluids Integrated Rack (FIR) and the Shared Accommodations Rack (SAR). The FCF Ground Segment includes an extensive amount of ground equipment and facilities that will support the operation of the FCF Flight Segment and facilitate experiment development, integration and ground processing. FCF ground racks similar to the flight racks will be used for hardware and software integration, experiment development, astronaut training, telescience operations and other essential Earth-based functions supporting microgravity fluid physics and combustion experimentation in the FCF.

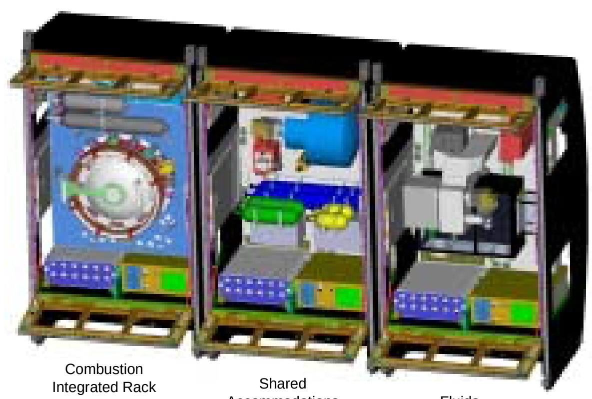


Figure 1 – The ISS Fluids and Combustion Facility

The CIR will be the first FCF rack deployed to the ISS. It will be launched on Utilization Flight (UF) 3 scheduled in January of 2005. The next FCF rack to be launched is the FIR in September of 2005 on UF-5. The Shared Accommodations Rack (SAR) will be the last rack to be launched on UF 6 scheduled in January of 2006. These FCF racks are incrementally deployed to ISS, and then fully integrated into the FCF System upon arrival of the SAR. They operate together with payload experiment equipment, ground-based operations facilities and the FCF Ground Segment to perform the required fluids and combustion science experiments within available FCF and ISS resources.

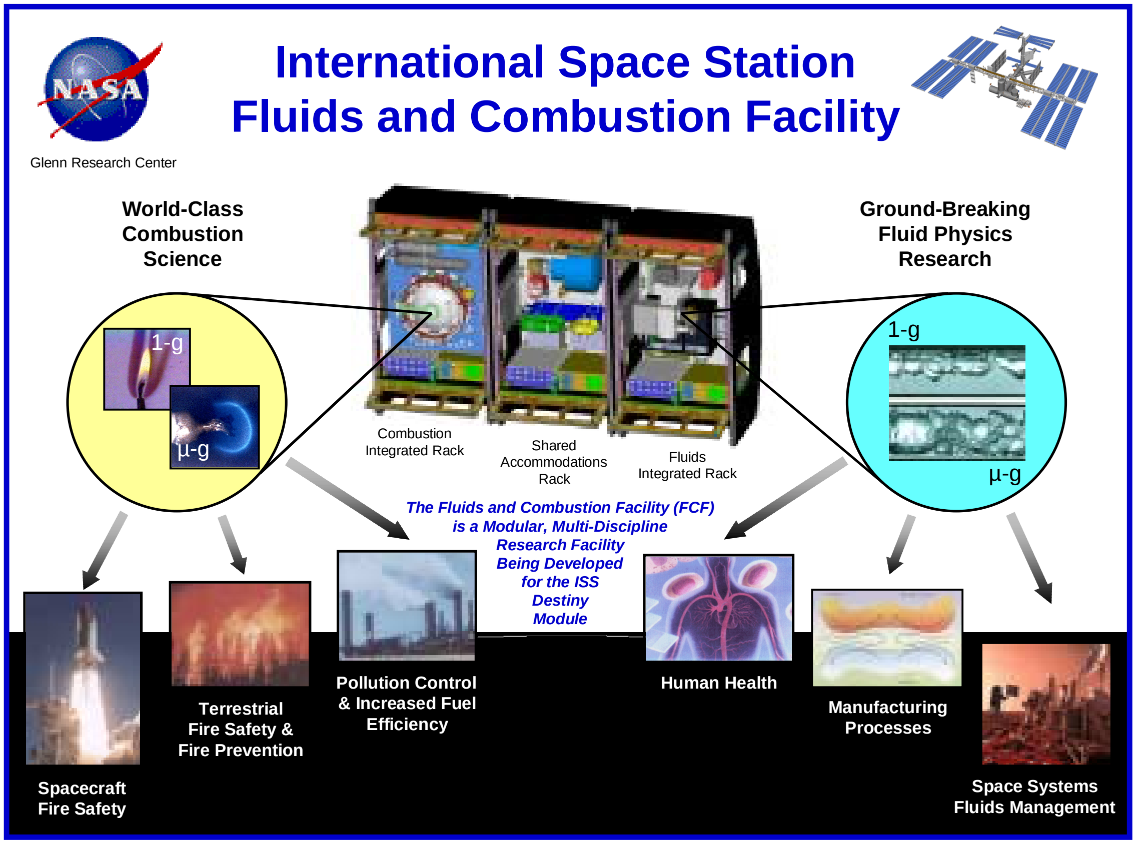


Figure 2 – Fluids and Combustion Facility Mission

FCF Mission

FCF's mission is to support the accomplishment of NASA's Human Exploration and Development of Space Microgravity Research Program objectives by facilitating sustained, systematic microgravity fluid physics and combustion science investigations on board the ISS (Ref. 1).

Combustion studies performed in the FCF will address sooting effects and the mitigation of fire risks for spacecraft fire safety. Combustion research will also result in methods, databases, analytical models and the performance of validating tests for material flammability characterization, improved combustion efficiency and fire hazard reduction strategies for spacecraft and terrestrial applications. Combustion scientists plan to conduct various microgravity combustion experiments in the FCF, including the study of laminar flames, reaction kinetics, turbulent combustion, smoldering combustion, droplet and spray combustion, flame spread, fire and fire suppressants, condensed phase organic fuel combustion, soot and flame-synthesized materials.

Fluid physics research performed in the FCF will provide a better fundamental understanding of natural phenomena affected by gravity and is expected to lead to enabling fluid system technology advancements and more effective fluid management systems for space, extraterrestrial and industrial applications. Experiments from five major fluids physics disciplines will be performed in the FCF; complex fluids (gels, foams, magneto-rheological fluids and granular systems); multiphase flow and heat transfer; interfacial and capillary phenomena; colloids; and dynamics and stability (drop dynamics, capillarity and magneto/electro hydrodynamics).

ISS Services and Resources

The FCF will occupy three contiguous rack locations in the environmentally controlled, pressurized ISS Destiny Laboratory Module. The FCF racks will utilize standard ISS services and will condition and distribute them for experiment use. Resources supplied to the FCF by the ISS include power, cooling water, gases, vacuum and command and data handling. ISS services and the estimated steady state resource allocation to each FCF rack location are shown in Table 1. The actual resources that the FCF receives from ISS may differ from Table 1 due to various activities that will be occurring in Destiny at any given time during steady-state operations.

ISS Service or Resource	**Expected Resource Allocation** (per FCF rack)
On-Orbit Volume (rack equivalent volume)	1.0 facility ISPR plus 0.8 - 1.0 m^3 (27 - *35 ft^3*) of stowage
Active Rack Isolation System (ARIS)	Attenuate low frequency (<100 Hz) on-orbit vibrations.
Up Mass	750 kilograms per year *(1653 pounds per year)*
Down Mass	*1.* 750 kilograms per year (*1653 pounds per year*)
Up Volume	1. 1.6 to 1.9 cubic meters per year (56 to *66 cubic feet per yr*)
Down Volume	1. 1.6 to 1.9 cubic meters per year (56 to *66 cubic feet per yr*)
Energy	1. 3200 kilowatt hours per year
Power - Main	1. 3kW, 120 VDC, 25 amp (non-current limiting)
Power – Auxiliary	1. 1.44 kW, 120 VDC, 12 amp (current-limiting)
Crew Time	1. 180 hours per year
Communications Downlink	1. 22.3 to 41.1 terabits per year
Communications Uplink	1. 1.1×10^{-4} to 1.7×10^{-4} terabits per year
ISS Command & Data Handling (C&DH) – Low Rate Data Line	1. 1553B Bus used for command, health and status data
ISS C&DH System – Med. Rate Data Line	1. 10 Base T Ethernet LAN user for inter-rack communications
ISS C&DH System – High Rate Data Line	1. Fiber optic data distributed interface used to transmit digitized, real-time video
ISS Communications and Tracking (C&T) System – Video	1. Pulse Frequency Modulated fiber optic (FCF analog video)
1. Moderate Temperature Cooling	45 – 338 kg/hr *(100 – 745 lbs/hr)*; 16.1 – 18.5 C *(61 – 65 F)*
2. Nitrogen	18.1 kilograms per year *(40 pounds per year)*; 517 – 828 kPa *(75 – 120 psia)*; 15.6 – 45 C *(60 – 113 F)*
3. Vacuum Exhaust System (waste gas vent)	276 kPa *(40 psia)*, max. Vent can accept gases at 15.6 – 45 C *(60 – 113 F)* and at a dew point of 15.6 C *(60 F)* or less
4. Vacuum Resource System	Access after reaching 1×10^{-3} torr
5. ISS Support Equipment	General purpose video; IVA tools; restraints and mobility aids; cleaning and housekeeping equipment; station support computer; portable fire extinguisher

Table 1 – International Space Station Services and Resources

FCF Flight Segment

The FCF Flight Segment will consist of the CIR, FIR, SAR and sufficient FCF equipment in ISS on-orbit stowage to support sustained FCF operations. Each FCF rack may operate with ISS independently (i.e., as a stand-alone rack). FCF racks may also operate together, via rack-to-rack data interconnections, for full FCF System capability. FCF equipment in stowage on board ISS will include flight spares and maintenance items. This equipment is needed to ensure sustaining operation of the facility between ISS logistics flights.

The modularity of the FCF will enable the development of payload hardware specifically suited for individual classes of fluid physics or combustion science experiments. The FCF systems are being designed for autonomous, remotely controlled and crew-tended operation, as required. Autonomous and remotely controlled operations maximize the amount of science that can be done on-orbit with limited ISS crew time. The FCF design allows easy manipulation, installation and removal of FCF hardware, which results in additional operational efficiency to minimize needed crew time. Science return from the FCF will be maximized through the use of a combination of highly automated systems, on-orbit physical component change-outs by the crew and software updates via ground commanding.

Combustion Integrated Rack

The CIR is configured to support microgravity combustion science experiments on board ISS (Ref. 2). The CIR incorporates an optics bench, combustion chamber, fuel and oxidizer management assembly (including gas supply systems), exhaust vent system, gas chromatograph, facility-provided combustion science diagnostics, power supplies, air and water thermal control subsystems, command and data handling avionics, a Space Acceleration Measurement System and various FCF common hardware and software items.

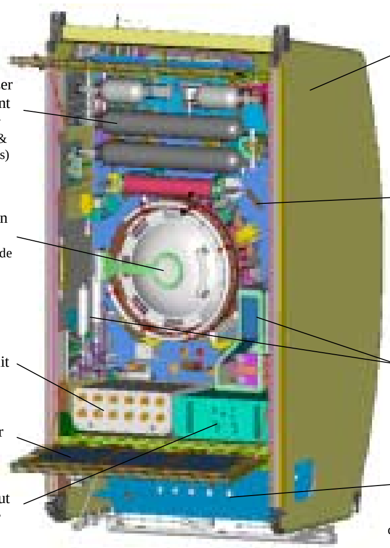


Figure 3 – FCF Combustion Integrated Rack

Combustion experiment equipment will be installed on-orbit in the CIR to customize it to perform many different combustion science experiments (Ref. 3). This PI-provided equipment will include an experiment insert that is installed in the combustion chamber for each investigation, experiment-unique combustion science diagnostics, avionics and software for a modular experiment computer that controls experiment equipment in the rack. The combustion chamber insert may include equipment such as a sample holder or burner, solid or liquid fuels, ignition source, flow duct, small diagnostics such as radiometers and experiment-specific instrumentation such as thermocouples. Consumable items such as solid and liquid fuels, exhaust vent filters and fuel, oxidizer and diluent gases are supplied by the Principal Investigator (PI).

Fluids Integrated Rack

The FIR is configured to support microgravity fluid physics experiments in ISS (Ref. 4). However, research from other science disciplines could also be supported in the FIR (or the SAR) owing to the large, flexible science platform in the FIR. The FIR features a large, user-configurable volume for experiments that resembles a laboratory optics bench. An experiment can be built up on the bench from components, or it can be attached as a self-contained package. Fluids experiments have widely ranging geometries. Many experimenters will build the scientifically unique aspects of their experiment into a small package that will be located on the front of the optics bench. Illumination sources and cameras, some of which will be FCF-provided and others PI-provided, will be mountable outside of or to each experiment package to cover the wide range of experiment imaging needs. These cameras and light sources can be rapidly removed and replaced after the optics bench is positioned. The cameras can then be final-positioned and operated by remote control from Earth.

Image processing, data storage and diagnostics control avionics needed for fluids experimentation will reside in the FIR. Experimenter's modular computers will be attached to the optics bench. Each experiment developer will provide PI-specific hardware and software that will customize the FIR to perform fluids experiments in the best way. This equipment may include special lenses for the illumination sources or cameras, circuit boards and software to be located in a modular experiment computer or other PI-specific items, such as an entire multi-user PI hardware apparatus.

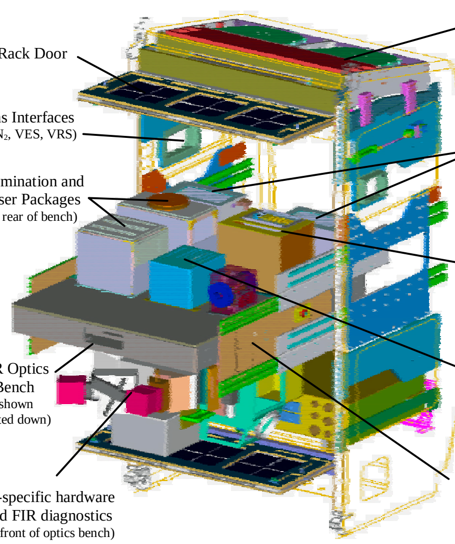


Figure 4 – FCF Fluids Integrated Rack

Shared Accommodations Rack

The SAR provides centralized command and data handling capability and multipurpose science volume needed to maximize FCF system effectiveness and meet FCF fluids and combustion utilization requirements. After the SAR is deployed, research may be supported in on-orbit configurations of up to three, interdependent FCF racks. Rack-to-rack data lines provide interfaces between FCF racks to permit interdependent rack operations.

The SAR will be both a repository for FCF shared avionics equipment and a rack where science experiments may be performed. Imaging and data capabilities in the SAR will include; 1) an Input/Output Processor for facility command, control, health and status monitoring, 2) two Image Processing and Storage Units (IPSU) for combustion and fluids image acquisition, processing and storage, 3) additional data processing capability for processing data from multiple experiments, 4) mass storage of FCF science data with removable media for return to Earth, 5) a video monitor for crew monitoring of the FCF, 6) a science avionics package for experiment data handling (i.e., for experiments performed in the SAR) and 6) an imaging interface for other Destiny Lab Module science rack usage.

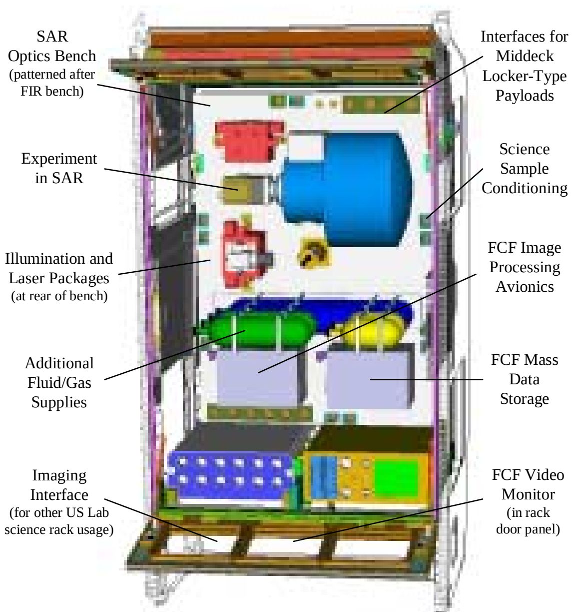


Figure 5 – FCF Shared Accommodations Rack

The SAR optics bench is patterned after the optics bench in the FIR. The SAR will provide additional FCF science accommodations to allow the FCF to meet research utilization requirements. The optics bench in the SAR allows experiment mounting, servicing and access, as well as experiment accommodations. Powered fluid sample preparation and storage accommodations and science sample conditioning provisions will be provided in the SAR. The SAR may also accommodate up to four, single middeck locker-sized payloads.

The SAR will provide options to enhance FCF System capability via upgrades. FCF upgrades envisioned after the SAR is deployed to ISS include; 1) the addition of an on-orbit calibration apparatus for FCF equipment requiring regular on-orbit calibration, 2) the addition of on-orbit logistical equipment to maximize FCF system readiness and throughput, 3) accommodation of multiple PI inserts so that PI hardware is available on-orbit at all times to maximize science return and experiment thru-put, 4) the storage of additional gas/fluid supplies to support CIR/FIR science operations and 5) the addition of FCF on-orbit chemical analysis capability for on-orbit fluid sampling and analysis.

FCF Common Hardware and Software

The FCF employs extensive commonality of design in the on-orbit rack hardware and software in order to optimize interchangeability, experiment throughput with available ISS resources and the accommodation of the various fluid and combustion experiments. The FCF uses various common, standard equipment items furnished by the ISS Program. Each FCF rack will utilize an International Standard Payload Rack (ISPR) in a four-post configuration (-4 ISPR) for the basic structure. Enclosing each FCF rack, in the front, will be two bi-fold doors. The rack doors provide acoustic emission attenuation, minimize air/thermal exchange with the cabin, reduce the amount of airborne contamination entering the rack and prevent stray light from entering or leaving each FCF rack.

The FCF will be outfitted with an Active Rack Isolation System (ARIS) for attenuation of structural-born vibrations emanating from the ISS, which enhances the microgravity environment for performing experiments. ARIS utilizes three accelerometers to measure the micro-gravity environment in the rack. Based on the measured accelerations, ARIS applies reactive forces, between the rack and ISS, through eight actuators to minimize transmission of vibratory disturbances.

Environmental control subsystems (ECS) in each FCF rack will utilize air and water to remove heat generated by FCF equipment and payload hardware. Air circulated throughout each rack will be cooled by an air-water heat exchanger located in the top of the rack. Cooling water from the ISS moderate temperature loop enters the rack and is split into two cooling loops. One cooling loop is dedicated to facility hardware, and the other loop is for payload hardware. Though the configuration of the ECS is somewhat different in the CIR than in FIR and SAR, many of the components of the ECS are common in all racks (Refs. 3,4).

Each FCF rack provides payloads with access to the ISS gaseous nitrogen and vacuum systems. These systems are available to support experiment operations such as the purging of experimental test cells and pressurizing or creating flows within experimental test cells. In the CIR, the vacuum

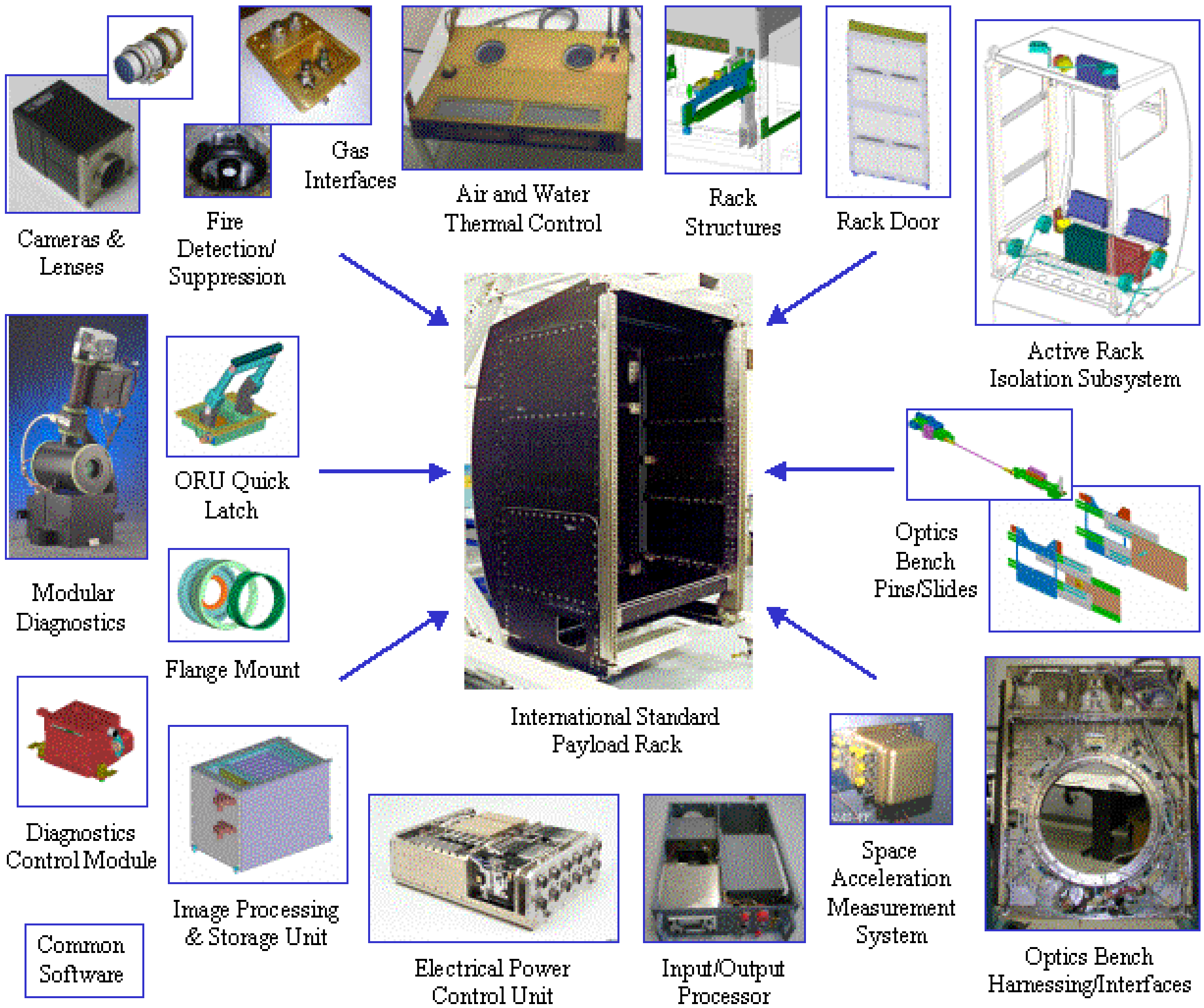


Figure 6 – FCF Common Hardware and Software

exhaust system (VES) is used to safely vent the chamber atmosphere after test completion (and during a test for combustion experiments that require flow through the chamber with active venting).

All power from ISS will flow through an Electrical Power Control Unit (EPCU) in each FCF rack to various facility and payload loads in the rack. The EPCU will provide power management and control functions, as well as fault protection (Ref. 5). The EPCU will take the 120 VDC power input from ISS and convert it to six, 120 VDC, 4 ampere fault-protected circuits and forty-eight, 28 VDC, 4 ampere fault protected circuits in each rack. The EPCU has the ability to draw power from the ISS main and auxiliary power buses and dynamically load share.

The Command and Data Management subsystems (CDMS) in each FCF rack provide command and data handling for both facility and payload hardware. A number of the avionics packages used in the FCF are commonly used in all of the racks. The Input Output Processor (IOP) used in each FCF rack provides the overall command and data management functions for each FCF rack, as well as the link from the rack to the ISS command and data management system via the MIL-STD-1553B, Ethernet, analog video and the High Rate Data Link interfaces. The IOP will receive and store science data from the science avionics package in each rack, image data from image processing and storage units (IPSU) in use in the rack and rack health and status data. The ISPUs and FCF Diagnostics Control Modules (DCM) will perform diagnostic control and image processing and storage functions in each FCF rack.

The modular software approach used for FCF employs the latest development tools and techniques, and object-oriented analysis to maximize software commonality, reusability and maintainability.

Flight Unit
FCF racks located on-orbit in the ISS US Laboratory Module

Experiment Development Unit (EDU)
High fidelity FCF model located at GRC. Available to payload developers for a variety of tests including interface verification, preliminary configuration selection, test sequence determination. Also used for sub-rack payload engineering model testing.

Ground Integration Unit (GIU)
FCF flight-equivalent racks located at GRC. The GIU is used for final flight interface verification between sub-rack payloads and the FCF, as well as acceptance testing of PI hardware. The GIU configuration may be maintained for on-orbit troubleshooting. The GIU is flight equivalent, except aluminum ISPRs are used and ARIS is not functional in the GIU.

Payload Training Center Unit (PTCU)
FCF training racks are located at JSC and used to train astronauts on FCF and sub-rack payload flight procedures. PTCU racks are supplemented with partial task trainers to prepare the ISS crew for experiment-specific operations.

Figure 7 – FCF Flight and Ground Units

On-orbit FCF software will be modifiable from the ground to allow autonomous operation of the FCF. Flight and Ground software will be modularized so that mission specific code sequences and parameters can be changed without reloading non-mission specific code, sequences and parameters. Embedded web software technology will be used at the crew laptop interface to the FCF on-orbit and at the PI interface to FCF data servers on the ground to allow users to interface with FCF embedded systems through a web browser running on the ISS crew laptop computer or ground data servers (Ref. 6).

FCF Ground Segment

For each FCF rack on-orbit, there will be three additional supporting racks on Earth. These are a Ground Integration Unit (GIU), an Experiment Development Unit (EDU), and a Payload Training Center Unit (PTCU). These ground racks are supplemented with a variety of other ground support equipment required to operate them, as well as simulator equipment that facilitates development of payload equipment for flight in the FCF. The Ground Segment also includes computer hardware and software at the GRC Telescience Support Center (TSC) to support telescience operations. Principal Investigators at remote sites will interface with the FCF System through the TSC and ground communication system interfaces.

Ground Integration Unit

The GIUs are flight-equivalent FCF racks that will be located at GRC and will provide the capability to simulate and trouble shoot on-orbit operations. The GIUs are also used for final, pre-flight integration and verification testing of payload equipment and/or facility upgrades. The GIUs will be identical to the Flight Units, except that the GIU racks will be Engineering Development Article (EDA) ground racks (constructed of aluminum) rather than flight ISPRs. Also, the GIUs will not include functional Active Rack Isolation Subsystem (ARIS) hardware. Testing in the GIU will include high-fidelity interface verification and an abbreviated mission simulation to fully exercise the hardware and software interfaces. The configuration of the GIU will be carefully controlled to use it for both simulating on-orbit operations and verification testing of payload hardware and facility upgrades prior to their launch to ISS. The PI, through his or her PI specific equipment development team, will have the capability to interact with the GIU when it is being used simulate or troubleshooting on-orbit operations.

Experiment Development Unit

FCF Experiment Development Units (EDU) located at GRC will be high fidelity models that will be very similar, though not identical, to the flight units. The EDUs will be derived from the engineering models of each FCF rack. The EDUs will be made available to payload development teams to support their experiment hardware/software developments and experiment configuration selection testing. The EDUs will also be used for pre-flight testing and early FCF to experiment interface verifications.

Payload Training Center Unit

FCF Payload Training Center Units (PTCU) located in the Payload Training Center (Building 5) at the Johnson Space Center (JSC) will support astronaut training on FCF and payload operations. The PTCUs will contain flight-like crew interfaces (i.e., same form, fit and function as flight), and will consist of mock-ups, brass-board level components and other non-flight components. The PTCU will include a standard experiment equipment trainer that can be used to train ISS crew members on the installation of a generic experiment apparatus or modular experiment computer.

The PTCUs will be designed to provide the crew with flight-like feedback, the ability to recognize nomenclature and graphics, experience with reach constraints, experience in manipulating stowage hardware and familiarity with how the rack interacts with other FCF racks and the overall ISS operations. The design will address training requirements for nominal operations, maintenance and malfunction scenarios. The PTCUs will be supplemented with part-task trainers, as necessary, to allow the crew to focus on specific training objectives (e.g., proficiency training for a particular task, such as card replacement).

PI Interface Simulators

PI interface simulators of FCF flight hardware will be made available to payload development teams to facilitate the development of fluids and combustion experiment hardware for the FCF. Simulator equipment will be designed to emulate those interfaces between FCF and the experiments that must be tested early and often. Simulators for electrical and C&DH interfaces (i.e., IOP, IPSU, DCM, EPCU, and science avionics packages) and facility-provided diagnostics will be provided by FCF. These simulators will be used extensively for preliminary interface verification testing between FCF and payloads.

Ground Support Equipment

Other ground support equipment (GSE), such as the Payload Rack Checkout Unit (PRCU), Suitcase Test Environment for Payloads (STEP), portable simulators of ISS interfaces, Mechanical Ground Support Equipment (MGSE) and Electrical Ground Support Equipment (EGSE), is required to support FCF operations. A PRCU located at GRC is capable of simulating all ISS to FCF interfaces, including the ISS power supply, Command and Data Handling (C&DH) system, Vacuum Resource System (VRS), Vacuum Exhaust System (VES), Moderate Temperature Loop (MTL) cooling water and the Nitrogen (N_2) gas supply. The PRCU will be used to emulate ISS interfaces for verification testing performed on the FCF flight units and for FCF and payload equipment verifications performed in the GIUs. The STEP simulates the ISS C&DH system, including the ISS Payload Multiplexer-Demultiplexer (MDM) and the Payload Ethernet Hub/Gateway (PEHG). The STEP is a portable unit that will be used to emulate ISS data interfaces for operation of the FCF EDU and to support FCF development testing.

Ground Facilities

Building 333 at GRC will be the primary integration and operations facility for the FCF and for FCF payload ground processing, integration and final verification testing. FCF rack integration, integrated testing efforts, operation of the FCF GIU, and operation of the FCF EDU will occur in this facility (Ref. 7). Final assembly and verification testing of the FCF racks comprising the FCF flight unit, the GIUs and the EDUs will be performed in Building 333, where the ISS Payload Rack Checkout Unit is located.

Various environmental and function/performance tests on FCF and payload hardware will be required prior to the deployment of flight units to the ISS. The GRC Structural Dynamics Laboratory, Microgravity Test Laboratory, Acoustics Test Laboratory, Electro-Magnetic Interference Laboratory, and Thermal Chambers at GRC will support the environmental testing. Performance testing will be conducted in Building 333 at GRC and at the FCF developer's facilities prior to flight unit deployment to ISS.

The GRC Telescience Support Center (TSC) will be the hub for flight operations and telescience activities associated with the ISS FCF. The TSC provides the capability to execute ground operations of on-orbit ISS FCF payloads and systems in coordination with the Marshall Space Flight Center (MSFC) Huntsville Operations Support Center (HOSC), the Johnson Space Center (JSC) Mission Control Center in Houston (MCC-H) and other remote ground control facilities.

FCF Development and Verification

An incremental approach to hardware and software development is being pursued to manage the fabrication and build-up of the various FCF flight and ground racks. At the rack level, the design of the FCF racks are incrementally refined as the hardware and software development progresses from the initial concept through delivery of the flight rack. At the facility level, incremental builds of the CIR, FIR and SAR ensure the flow of common design, components and lessons learned from one build to the next. This incremental approach will ensure on-orbit reliability, longer life and earlier science return for the FCF.

Where possible, FCF engineering models will undergo flight qualification and life testing to certify flight designs for launch and on-orbit operation, and the flight articles will be exposed to flight acceptance levels of testing only. This process will ensure that, to the extent possible, flight hardware is not subjected to the rigors of the qualification environments, which could potentially reduce life. After all planned engineering and flight qualification tests are completed, the engineering model of each FCF rack will be upgraded to become an Experiment Development Unit (EDU) to be used by PI hardware and software developers to facilitate payload developments.

Pre-launch verification of the FCF System, each FCF rack and FCF subrack payloads will be performed to ensure that the hardware and software meet requirements. Because the FCF is incrementally developed and deployed to ISS, FCF System verification testing will require a combination of flight unit, ground unit and simulator hardware. Final verification of FCF multi-rack operations (i.e., CIR, FIR and SAR) prior to launch will be conducted using the SAR flight unit with CIR and FIR ground integration units. Verification testing of the CIR, FIR, SAR and the initial increment of payloads to be flown in these racks will be performed prior to launch using the flight units. After CIR, FIR and SAR flight units are launched, the FCF GIUs will be used for final interface verification testing of all subrack payload flight hardware, facility upgrades and integrated FCF-payload configuration end-to-end testing.

FCF flight hardware and software will be accepted after on-orbit performance verifications are completed. Post-launch performance and state-of-health of the FCF System and individual racks will be checked after they are on-orbit. On-orbit performance verifications will involve setting up and operating FCF equipment and software in a widely scoped set of conditions to determine actual on-orbit performance. The initial installation, checkout, calibration and operation of the FCF racks on-orbit in the ISS will include the operation the first PI experiments in the FCF racks to verify system performance (i.e., the first combustion payload after CIR deployment and the first fluids payload after FIR deployment).

FCF Initial Payloads

Initial FCF payloads will employ multi-use equipment. Similar payloads (i.e., fluid physics or combustion science payloads from a given science sub-discipline) will be flown in groups in the FCF to reduce payload hardware and software requirements, increase the use of common payload hardware and diagnostics and conserve ISS resources.

Multi-User Droplet Combustion Apparatus

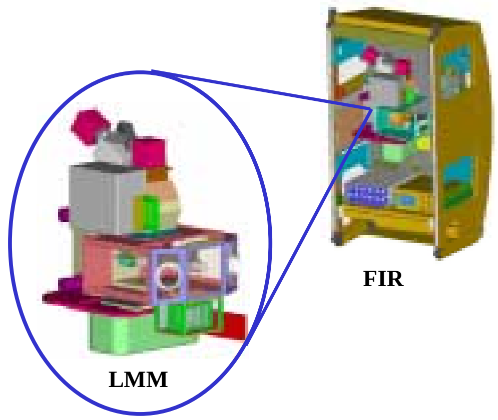
Droplet combustion experiments will be the first combustion experiments performed in the FCF Combustion Integrated Rack. These droplet combustion experiments will study small droplets of pure and bi-component alcohol and hydrocarbon fuels burning in an oxygen/inert gas atmosphere. Other droplet combustion investigations are planned, including the determination of sooting effects in droplet combustion and the effects of dynamic flow on burning droplets in microgravity.

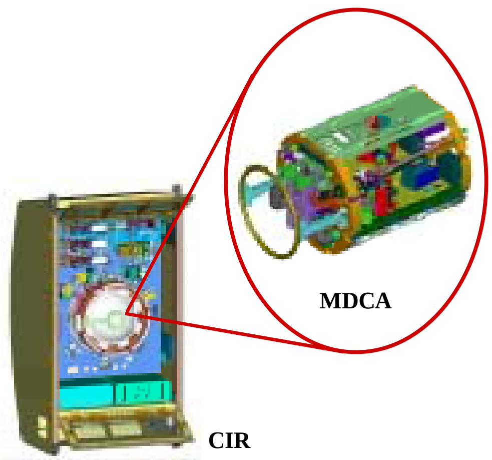
A multi-use payload apparatus called the Multi-User Droplet Combustion Apparatus (MDCA) will be utilized to support these experiments (Ref. 8). The MDCA will consist of a chamber insert, avionics package and droplet illumination package. The chamber insert will contain the droplet deployment mechanisms, hot wire igniters, a fuel supply system and a gas-mixing fan. Consumable items such as gas bottles and adsorber cartridges will also be required.

Following the MDCA, other multi-use and PI-specific payload hardware will be installed in the CIR to support solid combustion and gaseous combustion experiments that will be performed on board the ISS (Refs. 9, 10).

Multi-User Droplet Combustion Apparatus (MDCA)

Initial combustion experiments performed in the FCF will be droplet combustion experiments conducted in the CIR. These experiments will study small droplets of pure and bi-component alcohol and hydrocarbon fuels burning in an oxygen/inert gas atmosphere. The Multi-User Droplet Combustion Apparatus (MDCA) will be customized with PI-specific hardware to accommodate a minimum of four droplet combustion experiments.





Light Microscopy Module (LMM)

The LMM is a microscopic fluids research instrument featuring an imaging light microscope with laser diagnostics. Imaging techniques of high resolution color video microscopy, bright field, dark field, phase contrast, differential interference contrast, fluorescence and confocal microscopy are combined in a single LMM configuration with dynamic and static light scattering techniques to allow a very broad characterization of fluids, colloids and two-phase media. LMM will be installed in the FIR to accommodate a minimum of four to six fluid physics experiments.

Figure 8 –Initial FCF Fluid Physics and Combustion Science Payloads

Light Microscopy Module

The Light Microscopy Module (LMM) is a microscopic fluids research instrument featuring an imaging light microscope with laser diagnostics (Ref. 11). It will be installed in the FIR to accommodate the initial fluid physics experiments conducted in the FCF. Imaging techniques of high resolution color video microscopy, bright field, dark field, phase contrast, differential interference contrast, fluorescence and confocal microscopy are combined in a single LMM configuration with dynamic and static light scattering techniques to allow a very broad characterization of fluids, colloids and two-phase media.

LMM also incorporates a laser tweezers technique for sample manipulation. Initial fluid physics experiments support by the FIR and LMM will include studies of constrained vapor bubbles in microgravity, the studies of the physics of colloidal systems and investigations on hard sphere colloid growth, structure and dynamics in microgravity.

Following the LMM, other fluid physics payloads, such as the Granular Flow Module, will be operated in the FCF (Ref. 12).

FCF Operations

The FCF flight operations concept is driven by the need to conserve ISS resources, such as up mass and crew time. Therefore, FCF operations will be primarily autonomous and ground tended. Typically, once the crew sets up an experiment, the

FCF will execute a pre-planned experiment routine. Experiment progress will be monitored by ground operators, who will uplink commands based on experiment protocol. The primary ground operations site for FCF operations is the GRC Telescience Support Center (TSC). Both the TSC and any remote PI sites will receive the scientific data, which can be in the form of raw or processed images, sensor readings, etc. The PIs will be provided data from each experiment test point that they can use to plan the next point, if desired.

Flight Operations

FCF and payload hardware will generally be delivered to the ISS in a Multi Purpose Logistics Module (MPLM) in the Shuttle. After the initial installation and checkout of each FCF rack, on-orbit operations will consist mainly of reconfiguration, maintenance and payload operations. In order to minimize crew time, many FCF packages and hardware assemblies are designed as orbital replacement units (ORUs). When failure or performance degradation occurs, facility hardware will be replaced at the ORU level. On-orbit sparing of ORUs will be based on FCF reliability analyses. Payload equipment will be designed to allow on-orbit removal and replacement to update the scientific capabilities of the applicable payload configurations. Periodic recalibration may be necessary for certain FCF hardware, such as instrumentation, diagnostics and optics.

The Telescience Support Center (TSC) at GRC will house the console operators and provide the capabilities for payload commanding, telemetry acquisition, distribution, processing, ISS video displays and voice communication. Data transmitted to the console operators will consist of system monitoring information such as temperature, power and sample position, as well as video and other data essential to the operation of the overall facility and each specific experiment. Payload monitoring and science-related data will be available to investigators located at GRC or at remote sites where off-site monitoring capability has been established. The Space Acceleration Measurement System (SAMS) and Principal Investigator Measurement Services (PIMS) teams at GRC will provide raw and reduced acceleration measurement data to FCF users.

Logistics

FCF Integrated Logistics Support (IPS) will ensure that the FCF is available for science operations at least eight three percent (83%) of the time (i.e., ten out of twelve months) during each year of operation, the remaining time being used for FCF maintenance, upgrades and failure repair. FCF logistics support will facilitate control of on-orbit resource requirements for flight hardware to maximize the available crew time, on-orbit storage, power, data and resupply/return resources available for direct support of science. In addition, FCF logistics support will organize ground support infrastructure and resources to provide maintenance support for FCF flight hardware and support equipment, procure FCF spares and supplies, control FCF inventory of assets and provide access to technical data and documentation needed for ground and on-orbit maintenance.

Summary

The FCF is a modular, multi-user facility being developed by the NASA Glenn Research Center for permanent installation in the ISS Destiny Laboratory Module. FCF's mission is to support sustained, systematic microgravity fluid physics and combustion research on board ISS. The FCF is designed for highly automated operation of this equipment. This provides greater flexibility for science operations by the PI and greatly reduces crew time required to complete experiment test matrices.

The diverse complement of science to be performed in the FCF will be accommodated using three tiers of equipment. The FCF provides systems permanently installed in ISS and commonly needed by many fluids and combustion experiments. The FCF interfaces with ISS and delivers and conditions ISS resources for experiment use. The second tier of equipment is multi-use payload equipment (e.g., LMM, MDCA) that is installed in the FCF and customizes the facility to perform multiple experiments from a specific science sub-discipline. PI-specific equipment is the third tier of equipment. This equipment customizes the FCF and multi-use payload hardware for a given PI's experiment.

Commonality of FCF hardware and software is maximized across all racks and between subsystems. Commonality reduces hardware, software, and testing requirements, results in common FCF operational procedures to reduce crew effort for FCF operations, reduces the total number of FCF analyses, tests and designs, reduces overall FCF life cycle cost and allows common FCF sparing on orbit. The FCF implements a modular design, employing design features that facilitate ease of operation, reconfiguration, maintenance and upgrades. This allows interchange of orbital replacement units (ORUs) between racks, increases system flexibility, reduces stowage needs, reduces crew time, aids in sparing, provides for fault isolation and accommodates new ORU facility upgrades or the installation of new PI equipment.

FCF design features that reduce the need for limited ISS crew time resource include the use of quick disconnects for fluid lines, C-mount adapters for diagnostic packages and one-handed package change-out using a quick latch device. Deployable optics benches in the FCF allow easy access to both the front and the back of the optics benches, which also minimizes the crew time required to reconfigure FCF racks between experiments. Commonality of FCF optics bench designs for cooling, power, data and mechanical interfaces allow for interchangeability of packages between FCF racks. No tools are required for FCF reconfiguration. Standard connections for component and packages results in reconfiguration between experiments, which simplifies crew procedures, enhances ability to use packages between racks, minimizes stowage and reduces crew time required for reconfiguration between experiments.

Each FCF rack has stand-alone capabilities. The CIR and FIR are configured to primarily conduct combustion science and fluid physics experiments, respectively, although research from other science disciplines, commercial payloads and International Partner research can be accommodated. The SAR augments FIR and CIR capabilities to conduct experiments that cannot be fully accomplished by the FIR or CIR alone. The SAR improves FCF operational efficiency by providing capability to process data and downlink data from previous experiment runs while experiments continue in the FIR or CIR. Further, the SAR provides flexibility to off-load hardware from the optics plates in the CIR and FIR to create additional space for PI-specific equipment, enhancing science data return. Additional data storage and processing capability in the SAR allows for a greater number of test runs that would otherwise be precluded by ISS downlink limitations and/or a single rack's data handling capability.

The FCF Project is currently in the detailed design phase. Preliminary Design Reviews for the CIR, FIR and FCF System have been completed. The Phase I Fight Safety Review for the FIR and the Phase II Flight Safety Review for the CIR have been completed. Engineering models of FCF common hardware and the CIR have been constructed and tested. Critical Design Reviews for the CIR and FIR are planned in 2002. Additional information about the FCF may be found at the FCF World Wide Web site at ***http://fcf.grc.nasa.gov***.

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